

**Report from the Great Lakes Acoustic Workshop III  
Translation of acoustic data to fish abundance  
(and standardization of acoustic methods for the Great Lakes Region).**

**Lars Rudstam, John Horne and Guy Fleischer**

A workshop with participants from the Great Lakes region, North American and Europe was held February 11 – 12 at the Cornell Biological Field Station. The workshop was organized by Lars Rudstam, Cornell University, John Horne, NOAA –GLERL and Guy Fleischer, USGS-BRD and funded by the Great Lakes Fisheries Commission.

Day 1 of the workshop was devoted to several lectures and shorter presentations by the participants. The lectures included three presentations on theory and techniques and four case studies (Great Lakes, Rivers, Lakes, Marine):

Guy Fleischer, USGS-BRD, Ann Arbor, MI: Target strength of Great Lakes fishes

John Horne: NOAA Great Lakes Laboratory, Ann Arbor, MI: Theoretical scattering models for predicting target strength and the choice of operating frequency: applications to alewife and smelt in the Great Lakes

Patrick Sullivan, Cornell University, Ithaca NY: Survey design, introduction to the theory

Doran Mason, Purdue University. Acoustics in Lake Superior.

Kyle Hartman, West Virginia University: Acoustics in rivers – the Hudson experience

Paul Walline, Lake Kinneret Laboratory, Israel: Acoustics in lakes - the Lake Kinneret experience

Fredrik Arrhenius, Marine Laboratory, Sweden. Acoustics in oceans - Atlantic herring in the Norwegian Sea.

Various software were presented during the evening session. This session included presentations of

Biosonics Analyzer John Hedgpeth

Simrad EY and EP Frank Nutzen, Jeff Condiotty

HADAS Torfinn Lindem

HTI Patrick Nealson

EchoView Gideon Gal

Lake Ontario interfaces program Ted Schaner

Fish ID Pat Sullivan

Analysis and database system Brian Nagy

The second day was devoted to working group discussions. Three groups were formed, two discussing the translation of acoustic data to fish abundance and one discussion sampling design. The results were summarized and discussed by the whole group. What follows is a summary of the discussions and thoughts on issues that need to be resolved.

**Working Group 1 (Guy Fleischer Arrhenius, Einhouse, Hedgpeth, Kundsén, Nagy, Gal, Tipton, Warner, Nealson).**

Translation and Target Strength Issues:

- Absolute fish abundance estimation requires  $\sigma$  to be known

- What is the effect of single, dual and split beam methods on  $\sigma$ ?
- What is the effect of frequency on measurement of  $\sigma$ ?
- Can  $\sigma$  (or TS) be used to predict fish size?
- What threshold of individual echoes should be used?
- What is the effect of noise and depth on measures of  $\sigma$ ?
- Can different fish size/species groups be discriminated from TS distributions?
- What is the effect of invertebrates such as Mysis on measures of  $\sigma$ ?

It was recognized that the backscattering properties of fish are complex and may be difficult to predict under all conditions. However, it is a necessary evil if absolute measures of abundance are needed.

The group ranked the following issues in order of importance for discussion:

1. **Single target discrimination**
2. **TS as a predictor of size**

In addition, noise/depth effects, threshold effects, the multi-species issue, and frequency use were also deemed as important.

### Single Target Discrimination

Technique effects on  $\sigma$  are universal to single and multiple beam methods. In the words of Odd Nakken “Can we use *in situ*?” If we are to use *in situ*, we must develop guidelines to ensure  $\sigma$  is limited to individual echoes. Filtering single echoes is dependent on target densities and filtering algorithms.

Critical density was discussed. Multiple echoes occur when the density of targets is greater than the sampling volume. Critical density is defined as:

$$P_c = \frac{1}{V_c}$$

where the critical density ( $P_c$ ) is the inverse of the sampling volume ( $V_c$ ). Sampling volume is a function of pulse width, beam angle, and range. Traynor (1997) suggested a  $P_c$  value of 0.2.

Given the fact we have little ability to affect target density, it is important to use robust filtering algorithms. Since this is a fundamental and important processing feature, all users are warned to be aware of the filtering methods used. Different manufacturers may rely on different algorithms: these include quarter- and half-wave amplitude pulse width criteria, pulse width correlation, and possibly others. This was decided an important guideline, and the group would like to see more detail along this subject.

The technique of tracking was discussed. This method has the advantage of looking at individual fish over several samples (pings), but may be biased against smaller individuals.

### Target Strength as Predictor of Fish Size

This is the Holy Grail of fisheries acoustics. Given the understood complexities of backscattering, the use of any model whether simple regression or a more sophisticated model based on swimbladder morphology must be used with care. The utility of a predictive model must be demonstrated for the particular application; imported relations are probably good for a start but must be validated. The relation developed in Lake Michigan by Fleischer et al (1998) was found to be applicable to similar fish species in Lake Superior (as reported by Doran Mason). McClatchie et al. (1996a) concluded that the relation between target strength and fish size is species specific, and is affected by whether the fish are freshwater or marine, and dead or alive. This paper goes further to show that the regression of the quadratic form  $TS = 20 \log length + a$  is an inappropriate way to compare the target strength of different species. In a related work, McClatchie et al. (1996b) compared different backscattering models to the effects of fish tilt angle on target strength. They concluded that the greatest gains on target strength accuracy may be made from acquiring information on fish orientation, rather from the development of more elaborate modeling methods.

Since most fishes in the Great Lakes exhibit diel vertical movements, the group acknowledged that better measures of target strength may require more measures of individual fish as they migrate through the water column. Changes in target strength should follow a pattern of change that could be predicted by changes in tile angle and in pressure changes on the bladder.

### Threshold Setting

This aspect of target strength is of particular interest when smaller targets are highly prevalent. Understanding the food web organization in aquatic systems indicates there will always be smaller organisms, and that they may be of sufficient densities to interfere with acoustic measures of the smaller sizes of the organisms of interest. A prime example is Mysis and YOY fish in the Great Lakes. Generally, the group agreed that a minimum echo amplitude must be set to contain the targeted organisms, and a plot of target strength values will reveal if the relative contribution of smaller echoes is large enough to be of concern. If smaller echoes are predominant, then the acoustic sampling must take into account the smaller organisms. The expertise offered by the research by Gideon Gal may be used as a guide to this issue.

Further, thresholds and noise was discussed. The recommendation was to use passive listening to examine background noise in a particular situation. This affects  $20\log R$  data.

The remainder of topics were discussed in less detail due to time limitations.

### **Working Group II Translation (Rudstam, Ruby, Lindem, Mason, Jech, Walline, Schaner, Witzel, Klumb, Peitka)**

This group outlined a number of issues that need to be resolved to allow standardization of acoustic techniques. The issues were identified by the participants in order of importance as follows:

1. Can the shape of the TS distribution obtained in situ be used to assign densities of different species or size groups?
2. How can we standardize sampling and analysis of acoustic data?
3. What are the relationships between fish size and TS.
4. Development of new data acquisition software, including the use of more than one frequency.
5. How is spatial resolution in data processing affecting abundance estimates?
6. What are the effects of threshold values for echo integration and target strengths?
7. Validation of acoustics as a technique
8. Species identification
9. Interface between acoustic data and fish sampling, how to allocate acoustic data based on trawl samples
10. Error propagation
11. Single target identification algorithm
12. Dead zones close to the bottom and surface – how to deal with them.
13. Shallow water acoustics, horizontal beaming, effects on TS, etc.
14. Comparisons of different software packages.

This list can be summarized into two main issues. The first is related to differences between investigators in both hardware used and subsequent analysis. Those decisions were not often made based on rigorous analysis of the alternatives. Currently, 120 kHz is becoming a standard frequency for the Great Lakes. This may be as much a result of availability, small size of transducer, and history, as of a rigorous analysis of performance of different frequencies in the Great Lakes. Thresholds used in analysis varies among the investigators, as did resolution. The thresholds affect the amount of small targets that are included in the estimates. Some investigators used the same thresholds for echo integration as for target strengths, others used different ones. It was recognized that the echo integration threshold should be lower than the target strength threshold considered to be of interests, but there was no solution of how much lower. This depend on the degree smaller unwanted targets are present.

The second issue relates to in situ target strengths. In freshwater, in situ TS estimates are routinely used for scaling echo integration values and often used to assign a proportion of acoustic density estimates to different fish sizes. We recognized that there is not a one to one relationship between fish size and TS and the solution to this problem may be to develop distribution functions for what TS: s can be expected from a single fish. This is likely frequency dependent and depends on the method used. The solution could be empirical, where the distributions are obtained in situ while following individual fish, or theoretical by applying models such as the Rice pdf. We also need to document at what situations in situ target strength estimates are appropriate to use to scale echo integration values. Marine investigators are more restrictive in their use of in situ values than freshwater investigators, and we need to determine if a more restrictive approach is necessary. Guidelines are being developed in the marine field (Traynor 1997), and should be tested in freshwater. Such guidelines are dependent on the amount of multiple targets that can be tolerated and should be weighted to the advantage of using in situ estimates versus estimates based on models or on surrounding fish. Freshwater researchers have the advantage of being able to work mostly at night when fish are more dispersed and multiple targets less common.

### **Working Group III Survey design. (Horne, Sullivan, Hartman, Parrish, MacNeill, Parker, Condiotty)**

The consensus of the group was that most surveys in the Great Lakes were governed by the logistics of boat time and working constraints (i.e. work shift and overtime limits). Few surveys were designed primarily using statistical principles. The group felt that surveys designed for freshwater environments focused on ecological relationships while marine surveys have traditionally focused on abundance or density estimates.

#### Group Interests:

- sampling unit transect (does each location have equal probability of being sampled?) and within transect (how does autocorrelation change among transect subunits?)
- regular temporal sampling programs: should stations be repeated or re-allocated?
- transect layout: systematic or random? Layout of particular transects is not as critical as having each point in the area having equal probability of being sampled.
- calculating variance on whole samples vs. parts of samples (e.g. multiple size classes, species)
- sample "size"
- reporting variance, including measures of uncertainty and risk
- incorporating biological knowledge in survey design (e.g. spatial distribution)
- design for areas with multiple species that differ in size and spatial distribution
- multi-agency gear calibration if long-term collaboration
- recognizing and evaluating advanced methodology (e.g. adaptive sampling)

#### Group Issue Prioritized Summary:

1. Use Design Theory
  - recognize and evaluate advanced methodology
  - communicating results, uncertainty, and risk
2. Sample Unit, Number of Samples, Sample Layout  
Sample Timing: diel, seasonal
3. Incorporating Relevant Biological Knowledge  
Design for Multiple Species (variance of transect vs. variance of size class or species)
4. Systematic versus Random
5. Temporal Sampling Changes in Sample Layout

If Multiagency then Gear Calibration is Critical

#### Potential Exercises for the Great Lakes acoustic community:

Advantages of Using Design Exercises:

1. Quantify bias, uncertainty, and risk of designs
2. Example using Lake Ontario alewife abundance estimate based on 6 lakewide transects

Transect Layout Exercises:

1. Examination of a sample design layouts (systematic, random, zig-zag)  
Does each cell have equal probability of being sampled?
2. Overlay simulated population distributions

### 3. Examine effects of temporally-dependent distribution changes

#### Sample Unit Size Exercise:

Given a population distribution...

Is it 'better' to take 10, 1 unit samples or 1, 10 unit sample?

If no analytical solution...

2 boats, first crosslake transect, second several short transects

1 boat, several regularly spaced transects, subsample transects

### The Next Phase

Several of the issues raised were similar among the two translation working groups, although group I was more concerned with appropriate single target discrimination and group II more with standardization across platforms and software methods. In the summary discussion, we agreed that many of these issues should be addressed promptly, ideally this summer. This can be done through an inter-calibration workshop where researchers around the Great Lakes and elsewhere get together and compare output from different systems and different analysis packages. The effects of thresholds can be investigated at the same time and potentially, with the right fish densities, the effect of density on in situ target strengths. Doran Mason and Ted Schaner volunteered to prepare such a workshop proposal for submission to the Great Lakes Fisheries Commission. Such a workshop will move the process forward towards understanding how acoustic signals should best be translated into fish abundance. Issues that can be addressed include effects of

- a) frequency
- b) method (single, split, dual beam)
- c) analysis software
- d) thresholds
- e) fish density

An alternative to such a workshop, or in addition to it, is a suggestion by John Horne to conduct a weeklong "sound-off" in Cultus Lake, British Columbia, which would include issues of both translation and survey design. This lake has a known salmon population that can be used as a benchmark for acoustic results. The three commercial companies all have offices in Seattle and would provide equipment for this exercise. The exercise would have 4 objectives:

1. compare standard target calibrations among systems and among frequencies
2. compare abundance estimates of salmon populations using different gears, different survey designs, and different translation parameters
3. evaluate the hardware and methods used to acoustically assess fish populations
4. recommend minimum hardware standards, data outputs, assessment techniques

We also recommend that researchers collect stationary data this summer to get several measurements on single fish. Such data would allow for investigating the distributional properties of in situ target strength measurements and potential development of methods to separate fish sizes in TS distributions.

There was a consensus at the workshop that standardization of methods and discussion among acoustic users, especially within the Great Lakes community is a necessity. We are enthusiastic about the possibilities for moving towards such a goal. A number of action items were agreed upon at workshop

1. To conduct an intercalibration and comparison of methods exercise during the summer of 1999. Workshop proposal will be prepared by Doran Mason and Ted Schaner and sent to GLFC.
2. To ask GLFC to be the host for a web site on acoustic in the Great Lakes region. John Horne and Mike Jech have started developing this web site and volunteered to approach GLFC.
3. To collect stationary data during the summer of 1999, to be used for developing range of TS expected from single fish in different situations.
4. To investigate the possibility and gage interest for a workshop at Cultis Lake, BC, comparing different hardware and software methods on a known fish population. John Horne agreed to move forward on this task.

#### References

Fleischer, G. W., R. L. Argyle, and G. L. Curtis. 1997. In situ relations of target strength to fish size for Great Lakes Pelagic Planktivores. *Transactions of the American Fishery Society* 126:786-794.

McClatchie, S., J. Alsop, and R. F. Coombs. 1996a. A re-evaluation of relationships between fish size, acoustic frequency, and target strength. *ICES Journal of Marine Science*, 53:780-791.

Mc Clatchie, S., J. Alsop, Z. Ye, and R. F. Coombs. 1996b. Consequence of swimbladder model choice and fish orientation to target strength of three New Zeland fish species. *ICES Journal of Marine Science*, 53:847-862.

Traynor, J. 1997. Interpretation of in-situ target strength measurements. Presentation at 127<sup>th</sup> Annual meeting of the American

## User Background

Name, email	Experience	Workshop Expectations
Arrhenius f.arrhenius@imr.se	Acoustic surveys for fish abundance estimates (herring, sprat, larvae) in Baltic Sea.	Review incorporation of acoustic information in spatial distributions (diel migrations) in predator-prey models
Einhous dweinhou@gw.dec.state.ny.us	Basin-wide acoustic surveys of pelagic fish abundance in eastern Lake Erie for application to fish management.	Develop improved understanding of target strength-fish size relations, specifically for detection and discrimination of YOY and older fish.
Hedgepeth jhedgepeth@biosonicsinc.com	Doctoral studies of fish TS and density applied to smoothed expectation maximization method. Development of split-beam tracking system.	Development of distinct guidelines for determining and measuring "single targets".
Knudsen frank.reier.knudsen@simrad.no	Fish stock assessment in lakes and fixed location fish counting in rivers.	Review of frequency characteristics for best assessing bottom dwelling fishes, and TS measurement in the side aspect.
Nagy bnagy@fnr.purdue.edu	Stripped Bass assessment on the Hudson River; more recently assessment of pelagic fishes in Gulf of Mexico. Software development for the analysis and display of acoustic information in a GIS format using an intuitive user interface and seamless integration of separate software packages	Gain better understanding of the methods used to determine TS and abundance for acoustics and how better to standardize this process.
Pearsall wepearsa@gw.dec.state.ny.us	Recently involved in use of acoustics; assists in acoustic surveys performed in Finger Lakes of New York.	Gain better overall understanding of acoustics methodology.
Gal gg27@cornell.edu	Graduate studies of acoustic assessment of horizontal and vertical distribution of <i>Mysis</i> in Lake Ontario. Separate over-lapping fish and mysids by application of multi-frequency acoustic sampling.	Review issues related to multi-frequency sampling; specifically partitioning echo integration values into individual groups that overlap in distribution and acoustic size. Also, investigate the expected error associated with TS and it's translation to abundance.
Tipton rtipton@wvu.edu	Acoustic surveys to determine distribution and abundance of bay anchovy in Hudson River estuary.	Better understanding of translation of "raw" acoustic data to useful information.
Warner warnd49@oneonta.edu	Acoustic surveys of alewife in inland lakes in New York.	Gain better overall understanding of acoustics methodology.
Nealson consulting@htisonar.com	Involved in many mobile and fixed surveys using single, dual-beam, and split-beam systems. Applied studies that include differentiation of suspended macrophytes from adult salmon; statistical comparisons of lake population estimates derived from echo integration, echo counting, and target tracking algorithms; comparisons of split-beam and dual-beam TS distributions of entrained fishes for verification of single-beam models used to estimate passage.	Understanding validity of current quadratic TS-length equations and other methods available; evaluation of mobile survey designs in relation to low and high density conditions and various aggregation conditions.
Fleischer guy_fleischer@usgs.gov	Integration of acoustic and traditional capture techniques to best quantify abundance and distribution of important prey fishes in Great Lakes; investigation of relation of TS to fish sizes in mixed species situation. Use of	Contribute to the pool of applications of acoustic surveys in large freshwater systems and compare with other practical and theoretical experiences; both freshwater and marine.



	acoustics to assess recent invading population of rainbow smelt in inland lake system.	
Condiotty 75444.2172@compuserve.com	Represent Simrad in USA. Experience with both field and laboratory measurements	
Conners mec25@cornell.edu	consulting studies in fisheries, water quality and lake management, graduate research in sampling theory, time series and spatial statistics	discuss current problems and approaches in survey design and biomass estimation
Hartman hartman@wvu.edu	Fish (striped bass, bay anchovy, Atlantic tomcod, white perch, plus FW fishes in the Ohio River) abundance and distribution in the Hudson River Estuary and the Ohio River. Distributional ecology and relationships between fish distributions and physical structure. Comparison of river acoustics to rotenone survey estimates of fish abundance. Defining target-strengths of species in interest	
Horne horne@glerl.noaa.gov	Acoustic theory and practice in marine and freshwater.	
Jech jech@glerl.noaa.gov	Acoustic theory and practice in marine and freshwater.	
Klumb rak11@cornell.edu	Nearshore surveys of Lake Ontario.	
Lindem torfinn.lindem@fys.uio.no	Hardware/software, Electrical engineering, field studies across the world	
MacNeill dmacneil@cce.cornell.edu	Specialist New York Sea Grant and liaison to the New York Sea Grant Institute. Interests: Extension education, general hydroacoustic research, alewife and smelt abundance in Lake Ontario.	
Mason doran@fnr.purdue.edu	Fish (alewife, smelt, bloater, lake herring, other pelagic planktivorous species, larvae) abundance estimates and spatial distributions in Great Lakes (Michigan and Superior) and coastal ocean. Incorporation of spatial distribution and abundance into models of dynamic distribution/migration and dynamic predator/prey interactions.	
Parker slp21@cornell.edu	Starting work on smelt in Lake Erie.	
Parrish dparrish@nature.snr.uvm.edu	Smelt in Lake Champlain	
Pientka bpientka@zoo.uvm.edu	I am focusing on the analysis of acoustic data from a stratified random sampling scheme performed in three seasons (spring, summer, fall) using a single beam 200kHz system	I am interested in using acoustics to estimate rainbow smelt abundances and seasonal distributions in fresh water. Then relating this data to predatory demands (bioenergetics and spatial overlap) of Landlocked Atlantic salmon.
Ruby rjruby@mailbox.syr.edu	Fish (alewife, smelt, larvae) and mysid abundance estimates in deep New York inland	

		lakes (Finger Lakes). Incorporation of abundance estimates and spatial distribution for dynamic predator/prey models.	
Rudstam rudstam@cornell.edu		Fish (alewife, smelt, other species, larvae) and mysid abundance estimates in Great Lakes (Erie and Ontario) and deep and shallow New York inland lakes. Incorporation of spatial distributions (diel migrations, predator/prey overlap) in dynamic predator/prey models	
Schaner schanet@gov.on.ca		Monitoring of forage fish (alewife, smelt, and lately possibly threespine stickleback) in Lake Ontario - numerical abundance, biomass and recruitment	
Sullivan pjs31@cornell.edu		Survey design, models	
Walline paul@ocean.org.il		Seasonal and annual changes in fish abundance (by size class) in Lake Kinneret, Israel. Use of acoustic data in high resolution spatial models of fish bioenergetics (especially consumption).	
Witzel witzell@gov.on.ca		Fish (rainbow smelt, clupeids, shiners) abundance/biomass estimates in eastern Lake Erie. Differentiation of YOY and YAO smelt; standardize time series of acoustic data from two different systems (70 vs. 120 kHz).	

### Specific Acoustic Use Profile

Name	Frequency uses	Marine or freshwater	In situ Method	TS threshold	Biological Sampling	Vert/Horiz Resolution	Application of species composition	Use of TS for size distributions
Arrhenius	38 kHz (some 70 & 120)	Marine and brackish up to 150 m depth	Mobile split beam	Collect – 80 dB, process – 60 dB	Midwater trawls	1 nm × complete water column	Yes	no
Einhouse Witzel Connors	120 and 70 kHz	FW lake Erie	Mobile single and split beam	Collect – 70 dB process – 60dB	Midwater trawl	5 min × 4 thermal zones	Yes, but mostly smelt	Yes to discriminate YOY
Hedgepeth	70 kHz	Marine <30m depth	Mobile split beam	-80 to -70 dB	Midwater trawl	0.5 nm × 3 m	Roughly	No
Knudsen	120 kHz	FW riverine	Fixed, split beam	-45 - -40 dB	None	Echo count	Catch data from fishery	attempted

Nagy	120 kHz	riverine estuary and marine	Dual and split beam mobile	-80 to -70 dB	Midwater trawl	20 pings × 1 m	Yes	On Hudson R. work
Gal	420 and 70 kHz (some 120 kHz)	FW (Great Lakes) and marine	Single, dual and split beams mobile	-100 dB for Mysis -64 dB for fish	Neuston tows for Mysis	Variable horizontal × 1-2 m vertical	N/A	No
Tipton Hartman	120 kHz	Estuary < 30m	Split beam mobile	-70dB	Oblique midwater trawls	20 pings × 1 m	Yes	Yes
Warner	120 and 70 kHz	FW inland lakes	Single and split beam mobile	-70 dB	Midwater trawls and gill nets	300 pings × 1 m	Yes	No
Nealson	200 to 420 kHz (some 38)	FW	Evolved from single to dual to split beam for fixed and mobile	-56 dB	Midwater trawls	Echo count	Yes	Yes, with trepidation
Fleischer	120 and 420 kHz	FW; Great Lakes up to 150 m, inland < 50 m depth	Dual and split beam mobile	Collect - 75 dB and process - 60 dB; - 95 dB for Mysis	Midwater trawls for fish; neuston nets for Mysis	Great Lakes: 10-m depth zone × 5 m Inland: variable horizontal × 2 m	Yes	No
Condiotty								
Horne								
Jech								
Lindem	70kHz	inland lakes	single, split					
Mason	120 kHz	Great Lakes	dual, split					

Parrish Pientka	200 kHz	Champlai n	split					
Rudstam Ruby Klumb	70, 120, 420 kHz	Various	single, split, dual					
Schaner	120, 420 kHz	Ontario	dual, split					
Walline	120, 420, 70 kHz	Kinneret	single, dual					